Fire Fuel Protocol

Purpose

To measure the different types of fuels (i.e., dead branches, logs, live shrubs and trees) for fires in land cover sample sites

Overview

In a homogeneous land cover sample site, students measure tree, shrub and herbaceous cover and heights. Using a compass and tape measurer, students walk along transects and count the different sizes of downed woody fuel types. Students use clinometers to measure the overall slope of the site as well as the slope of each transect.

Student Outcomes

Students learn about the different types of living and dead organic materials that can become fuels for wildland fires.

Science Concepts

Physical Sciences

Objects have observable properties that can be measured using tools.

Life Sciences

Ecosystems demonstrate the complimentary nature of structure and function.

Geography

Physical processes shape the environment.

Science Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

2-3 hours excluding travel time

Field time will lessen with experience

Level

Middle and Secondary

Frequency

Collect data once for each site.

Multiple Fire Ecology Sites are desired.

Materials and Tools

GPS Data Sheet

GPS Field Guide

Fire Fuel Center Plot Data Sheet

Fire Fuel Center Plot Field Guide

Fire Fuel Transect Measurements Data Sheet

Fire Fuel Transect Measurements Field Guide

MUC Field Guide and/or *MUC Glossary of Terms*

Data Sheets and *Field Guides* for *Biometry* and *Land Cover Sample Site Protocols* in the *Land Cover/Biology Investigation*

GPS

Wooden stakes

Flexible tape measure, at least 30 meters

Compass

Clinometer

Camera

Tree guides

0.5-0.65 cm wooden dowel

2.5 cm wooden dowel

2 clear rulers in mm

Meter stick

Trowel

Clipboard

Pencils or pens

Flagging

Landsat image, topographic map, other maps of area (optional)

Preparation

Locate a Fire Fuel Site.

Practice using the *Land Cover Sample Site* and *Biometry Protocols* in the *Land Cover/Biology Investigation*

Learn about the different fuel classes.

Welcome Introduction **Protocols** Learning Activities Appendix

Fire Fuel Protocol – Introduction

Why measure fire fuels at land cover sample sites?

For thousands of years, fires have shaped the wildlands in many places around the world. But wildland fires can be very different. For instance, fires burn grasslands every year, while certain forests and wetlands escape fire for centuries at a time. In forests, fires may burn only grass and low shrubs under large trees or nearly every tree may be killed. Fires can produce a mosaic of fire-killed trees and patches left unburned because of random changes in wind direction or other conditions (Brown and Smith, 2000). The outcome of fire is unpredictable and plays out differently in nearly every plant and animal community.

Many plant and animal species continue to persist for thousands to millions of years although their ecosystems are periodically ravaged by fire, and some species even thrive when their homelands burned at predictable intervals. Not surprisingly, certain plants and animals have evolved traits that enable them to take advantage of fire to reproduce successfully or compete with other species (Miller, 2000). Some wild plants and animals are actually harmed if fire is excluded from their habitat. In these environments, land managers often attempt to reintroduce fire and take advantage of naturally occurring fires to benefit these landscapes. Professional programs that include preventing fires, putting them out where they are likely to produce damage, and using them to benefit the land is called fire management.

Wildfire scientists refer to all the organic plant matter above the ground as fuel. The amount and kinds of fuel help determine how far and fast a fire spreads, and the relative fraction of live and dead plants are burned. Student measurements will help scientists make better models for calculating fire risk. These improved models could save lives, protect property, and improve fire management. As well, your data can be used to calibrate detailed fuel maps created from satellite imagery.

In addition, the measurements you take can be used for other types of research and management. For instance, the estimates of live and dead biomass made from your measurements are extremely important for understanding carbon, water and nutrient cycles. Potential smoke and carbon inputs to the atmosphere can be calculated from the loadings of fuels computed from your data. Maps of the habitats for mammals, birds, reptiles, amphibians and insects that utilize coarse woody debris (the downed logs) can be made.

What are fuels?

Fuels are the above ground organic biomass that can contribute to a wildland fire. Fuels are usually classified by whether they are live or dead, woody or herbaceous, and size. The classes of fuels used in this protocol are shown in Table FF-1.

We classify fuels as either live or dead because of their differences in moisture content. Moisture content in fuels plays a major role in fire behavior. Live fuels are living plants extracting water from the soil. Since live fuels are constantly extracting water from the ground, their moisture content tends to be quite high. Dead fuels no longer manufacture food or circulate water so their moisture contents are more closely linked to atmospheric conditions.

Live fuels are separated into trees, shrubs and grasses. Shrub fuels include all those living woody plants, including young trees that can burn during a fire. Herbaceous fuels include all non-woody plants such as grasses, sedges, forbs, and ferns. In the MUC definition (see *Land Cover/Biology Investigation*), trees are defined as woody vegetation greater than 5 meters tall.

Dead fuels can be parts of living plants or dead organic material lying on the ground. Dead woody fuels found on the ground are called downed. Dead woody fuels are the most important for the spread of wildfires and the most influential for how a wildfire behaves. Downed dead woody fuels are divided into size classes based on the diameter of the fuel particle (Table FF-1). These diameter classes were developed to describe the time it takes for the woody particle to dry. Other dead fuels can be the suspended dead plant parts from live trees, shrubs, or grasses. The weight or mass of dead or live fuels per unit area (e.g., kg m^{-2}) is called loading, and fuel loading is one of the most important quantities that will be calculated from the data you collect.

Fire Behavior and Effects

Fire behavior is the way a fire reacts to its surroundings. How a fire behaves depends on the "fire environment", a term used to describe the type and amount of fuels present, weather, and topography in an area. The most commonly used fire behavior characteristics are fire spread (how fast a fire moves) and fire intensity (the flame length). Sometimes even the most intense fires do not heavily impact the environment, and sometimes the smallest flames can kill many plants. The term, "fire effects", is used to describe the damage or influence a fire has on the biota. In addition, the term, "fire severity", is the damage that heat from fire can have on living organisms above and below ground. Low severity fires kill few living flora and fauna, but they may have high fire intensity and fast spread rates. The potential fire behavior and fire effects cannot be predicted without an accurate description of the fuels.

Table FF-1: Fuel Types and Size Classes Used in Fire Management. The classes of fuels used in this protocol. The diameters of the downed wood are often referred to the average length of time it takes to dry the wood.

Fuel Type	**Size** (twig, branch, or trunk diameter)	**Description**
Crown Foliage	Any	Living and dead crown foliage including needles and broad leaves
Crown Branchwood	0 to 3 cm	Live and dead crown woody branches
Shrub — Live	Any	Living woody plants – trees and shrubs less than 2 meters tall
Shrub — Dead	Any	Dead shrubby material suspended above ground. This includes trees and shrubs less than 2 meters tall.
Herbaceous - Live	Any	Live herbaceous plants including grasses, sedges, forbs, ferns, and lichen
Herbaceous — Dead	Any	Dead herbaceous plant parts above ground
Litter	None	Recently fallen needles, leaves, cones, and bark
Duff	None	Partially decomposed organic material below the litter layer
Downed Woody	0 to 1 cm	Takes 1 hour to dry woody twigs and branches
	1 to 3 cm	Takes 10 hours to dry woody twigs and branches
	3 to 8 cm	Takes 100 hours to dry woody branches
	8 + cm	Takes 1000 or more hours to dry branches and logs

Teacher Support

Site Selection: Where and When

The measurements are taken within a homogeneous area of land cover that is at least 90 meters by 90 meters in size. Refer to the *Land Cover/Biology Investigation* for more discussion. Fuels are often correlated with the surrounding plant community and topographical setting. It is best to confine your fuel sampling to an area that has similar vegetation characteristics along with similar slope, aspect, and elevation. Aspect is the general direction the slope the sample site faces. This homogeneous area is often called a stand in ecology or forestry. Stand characteristics can change over a very short distance, sometimes within 3 to 5 meters. Take measurements at your site that best represents the conditions in the stand based on the living vegetation (species composition, plant structure, plant size, canopy closure), the stand's history (stumps, burned logs, fire scars), ground characteristics (fuel loadings, duff depths), and topography (slope, aspect, elevation).

The protocol asks students to measure canopy cover. Because of this, the best time to perform the protocol is when the leaves are open.

Measurement Procedures

Sampling for the *Fire Fuel Protocol* is divided into two parts. One set of measurements is made within a center 30 x 30 meter plot and a second set of detailed measurements is made along other transects outside the plot. For the center plot measurements, students will take measurements following *the Land Cover Sample Site Protocol* and *Biometry Protocol* in the *Land Cover/Biology Investigation.* In addition, students will be taking slope, aspect, and average stand and crown heights. The second group following the *Fire Fuel Transect Protocol* will be taking a different set of measurements. The Fire Ecology measurements can be taken in all natural MUC land cover types (MUC 0,1, 2, 3, 4, 5, and 6) except open water (MUC 7).

There are two versions of the field guide: a more descriptive classroom preparation guide and a short field guide. The classroom preparation guide provides more background on how to do the measurements and the students can use this version to practice and become comfortable with taking the measurements. The other version provides a list of shorter directions to be used in the field.

True rather than magnetic compass directions are used. Refer to the *GPS Investigation* to learn how to correct for magnetic deviation in your area.

Mark the tape with brightly colored paints or flags at the 5-meter, 7-meter, 10-meter, 15-meter and 25-meter marks so that you can easily identify where you are on the transect when sampling.

Secure an 8-10 cm nail to the zero end of the tape with string or wire making sure the tape doesn't move. Drive this nail into the ground at the beginning of a transect. The nail should be short enough to be pulled out of the ground by pulling on the 25-meter end of the tape, but long enough to keep the tape from moving or dislodging at the slightest tug. The use of the nail allows fuel sampling with only one person. Once the person has traversed the entire length of the transect, he or she can simply pull the nail out of the ground by tugging on the 25-meter end, and begin the next transect.

Student Management

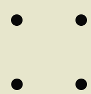
You may want to divide your students into two main groups (one for the center plot and the other for the transects) and allocate responsibilities for each group. There are separate field guides and data sheets for the plot and detailed transect measurements.

A two- or three-person fuel sampling team is recommended per transect. More people often trample the fuel bed, which can make the measurements inaccurate. A single person can perform these measurements but will have a difficult time collecting these data until experienced with the methods.

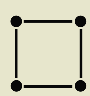
Each team should have two wooden dowels each with a different diameter. The first dowel should be from 0.5-0.65 cm in diameter. This is used to determine the diameters of the 0— 1 cm class (1-hour fuels). The second dowel is 2.5 cm in diameter, which is used to measure the diameter of 1 – 3 cm class (10-hour fuels). Refer to Table FF-1.

How to Count Fire Fuels

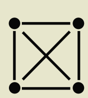
The following box illustrates an easy method to keep track of the fuel counts along transects. Instead of counting the intersects in your head and recording the final tally, try using a box tally method where you put a dot for each fuel intersect. The dots are arranged in a pattern that creates four corners of a box. Each dot is for one count for a total of 4 counts shown below.



Now each additional fuel count tally is a line connecting the dots. Each line is one count. The total in the picture is 8.



The final two tallies are crosses through the middle of the box. Each diagonal is one count.



Each completed box represents 10 fuel intersect tallies for that size class

Connections to Other Protocols

Land Cover/Biology: In order to do the *Fire Fuel Protocol,* students need to perform the *Land Cover Sample Site* and *Biometry Protocols*.

Atmosphere: The potential for fire is related to the atmospheric conditions such as temperature and precipitation.

Phenology: The amounts of dead and living matter are dependent on the time of year, particularly if there is a distinct wet and dry seasonal pattern, or cold and warm seasons at your locality.

Helpful Hints

Putting completed *Data Sheets* in plastic bags in the field will help to keep the forms from getting wet or dirty.

Questions for Further Research

Is fire common in your area? If so, what kinds of adaptations have plants and animals made for these environments?

What time of year do wild fires most occur in your area? Why?

Are certain land cover types more susceptible to fire?

After a fire happens in your region, what types of plants first grow there?

Classroom Preparation Guide for Fire Fuel Center Plot Measurements

Overview

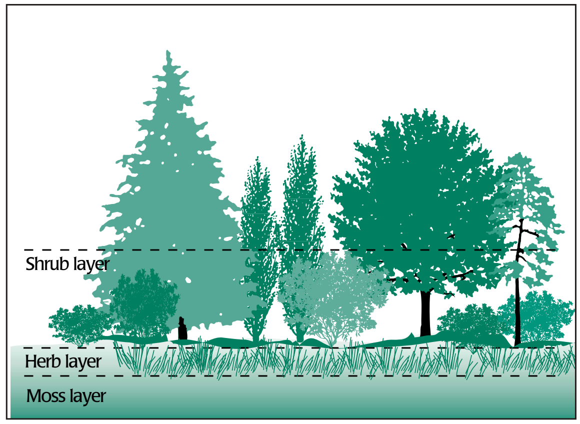
One set of measurements is taken within a 30 x 30 meter area within your homogeneous site, like that described in the *Land Cover/Biology Investigation*. These measurements describe the general characteristics of the stand as a whole. A second set of measurements is taken on several fuel transects around the center plot. These fine scale measurements will describe the fuel loadings, live and dead shrub and herbaceous cover, and duff and litter depth.

In the Field

The center 30 x 30 meter plot

1. Do the *Land Cover Sample Site* and *Biometry Protocols* in the *Land Cover/ Biology Investigation.* Identify latitude, longitude and elevation using a GPS, take photos and identify the MUC class. Do the full set of biometry measurements: ground and canopy cover, tree and shrub heights, dominant and codominant tree and shrub species identification.
2. Measure the aspect of the site. Aspect is the general direction the slope of the site faces. This is measured by standing perpendicular to the slope of the site with your eyes facing uphill. Measure the direction with the compass (1-360 degrees). Be sure to enter the true (not magnetic) directions. An aspect value of zero is entered for flat stands with no slope. 360 degrees is used for true north.
3. Work with another student who is approximately your same height. Measure the angle of the slope of the site by aiming your clinometer downhill 25 meters away. Look through the straw of the clinometer and locate the eyes of the other student. Record the angle on the *Fire Fuel Transect Measurements Data Sheet*. If you are looking downhill, turn the clinometer around, locate the eyes of the other student and record angle. Then, look upslope and repeat the procedure. Record second slope value.
4. Estimate the average stand height. The average stand height is the average height of all trees or shrubs in the dominant tree stratum. The forest canopy is composed of layers or strata that are defined by the heights of the associated trees and shrubs.

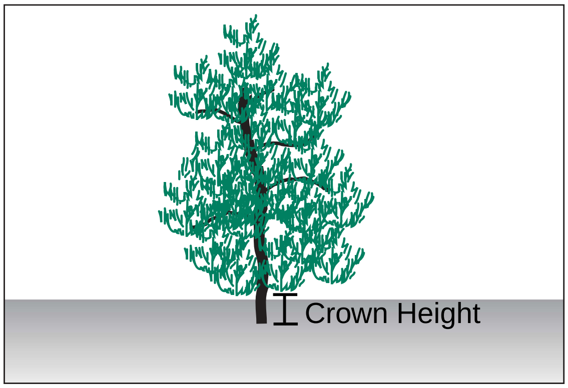
Figure FF-1: Demonstration of a Plant Strata in a Forest Community



There needs to be at least 10 percent canopy cover to define a stratum. Sometimes the dominant stratum is composed of trees and shrubs of variable heights. You can estimate this with your eyes. To make a better estimate, you can use the clinometer or tape measure to measure a few trees or shrubs heights in the dominant stratum. If the trees or shrubs you already measured are in the dominant stratum, then calculate the average stand height from those measurements.

5. Estimate the average crown height. The average crown height is the average height of the live crown base of the lowest tree/ shrub stratum (i.e., to the bottom of the crown of the lowest tree/shrub stratum). Again, there needs to be at least 10 percent canopy cover to be considered a stratum. Because the crown heights can be very variable, you should measure and record the crown base heights of all trees/

Figure FF-2: Crown Height is the Distance from the Ground to the First Branches



shrubs in the lower layer and then calculate the average. If the crowns are close to the ground, use a meter stick or flexible tape measure to measure the crown heights. For taller trees use the clinometer to measure heights following the method described in the *Land Cover/ Biology Investigation*. Sometimes, the crowns of trees/shrubs will touch the ground, and if there is over 10 percent cover of trees/shrubs that touch the ground, a crown base height of zero is recorded on the *Fire Fuel Center Plot Data Sheet*.

6. Record any comments that may be relevant to the fuels data. Include knowledge of stand history (grazing, fire, timber harvesting evidence), unusual stand conditions (e.g., insect and disease infestations, animal browsing), and problems with sampling (e.g., slope too steep for secure footing). Write a generalized description of the location of the site. Include estimates of distances and azimuths from roads, trails, and rivers, and record any place names that might be relevant.

Detailed Measurements Along Transects

Overview

The number of transects you take measurements will vary, from 3 to 7, depending on how many fuel particles cross your transects.

This fuel transect methodology uses a planar approach pioneered by van Wagner (1968) and improved upon by Brown (1974). This procedure uses a sampling plane to count all the intersections of downed woody fuel (Figure FF-3). The sample plane starts at the ground surface and extends 2 meters vertically above the ground surface. All downed woody fuel particles (twigs and branches) that intersect that plane are counted. Visualize a pane of glass that extends 2 meters upward from the ground where every woody twig or branch that the glass slices gets counted (Figure FF-3). Place a flexible tape along the ground and that becomes the bottom of your sampling plane that extends 2 meters high. Since often the ground is not flat, the top of the sampling plane wavers with the topography of the ground surface.

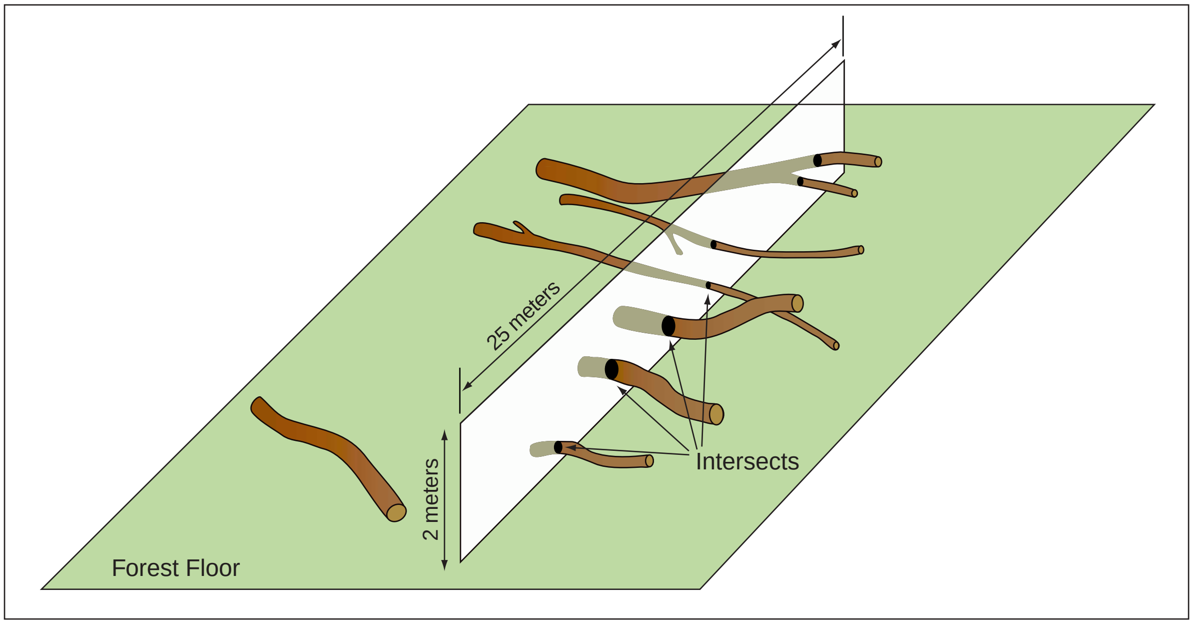
Downed woody fuels intersecting the sampling plane are counted in four size classes of 0 - 1 cm diameter, 1 - 3 cm diameter, 3 - 8 cm diameter, and 8+ cm in diameter (Table FF-1).

In the Field

Part 1: Measurements taken between the 5-meter and 15-meter marks along a transect

1. Drive the attached nail at the zero end of the tape into the ground next to center flag or stake. All fuel transects are 25 meters long but fuel intersections (where twigs and branches cross the transect) will be counted from the 5 to 25 meter marks. The first 5 meters is skipped to avoid excessive trampling of fuel bed near the center. The tape is stretched due EAST (90 degrees azimuth from the center of the site). The tape need not be level because fuels are estimated along slope distances rather than horizontal distances. You can wrap the other end of the tape (after 25-meter mark) around a tree or shrub, or

Figure FF-3: Important Line Transect Distances for Fuel Measurement

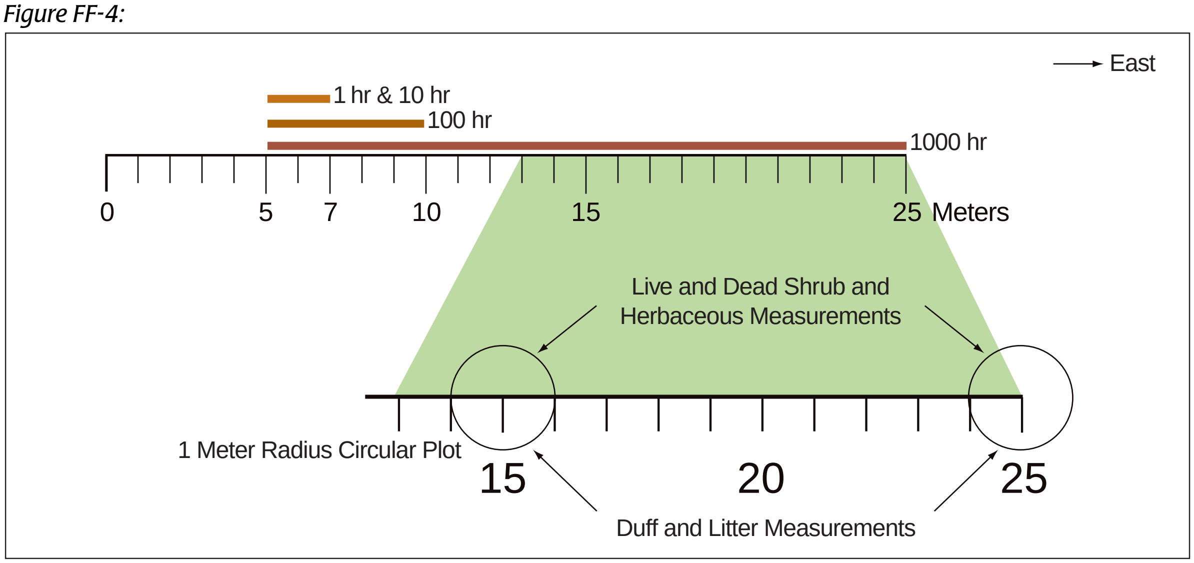


lightly anchor it to the ground with another nail. Keep the tape as taut and straight as possible. You may attach another nail at the 30-meter end of the tape but this prevents rapid coiling or reeling of the tape after you are finished. Be very careful not to disturb any fuels along the entire length of the tape, especially between the 5- and 10-meter marks. Many people have a tendency to shuffle along the line and kick the downed woody particles.

Figure FF-4 below illustrates where the Fuel Measurements are taken along each transect.

- From the 5-meter to 7-meter mark, sample all fuels that cross the sampling plane: the 0 – 1 cm twigs, 1 - 3 cm twigs and branches, 3 - 8 cm branches, and 8+ cm logs.
- From the 7-meter to 10-meter mark, count the 3 – 8 cm and the 8+ cm logs.
- From the 10-meter to 25-meter marks, only count the 8+ cm logs.

Figure FF-4:



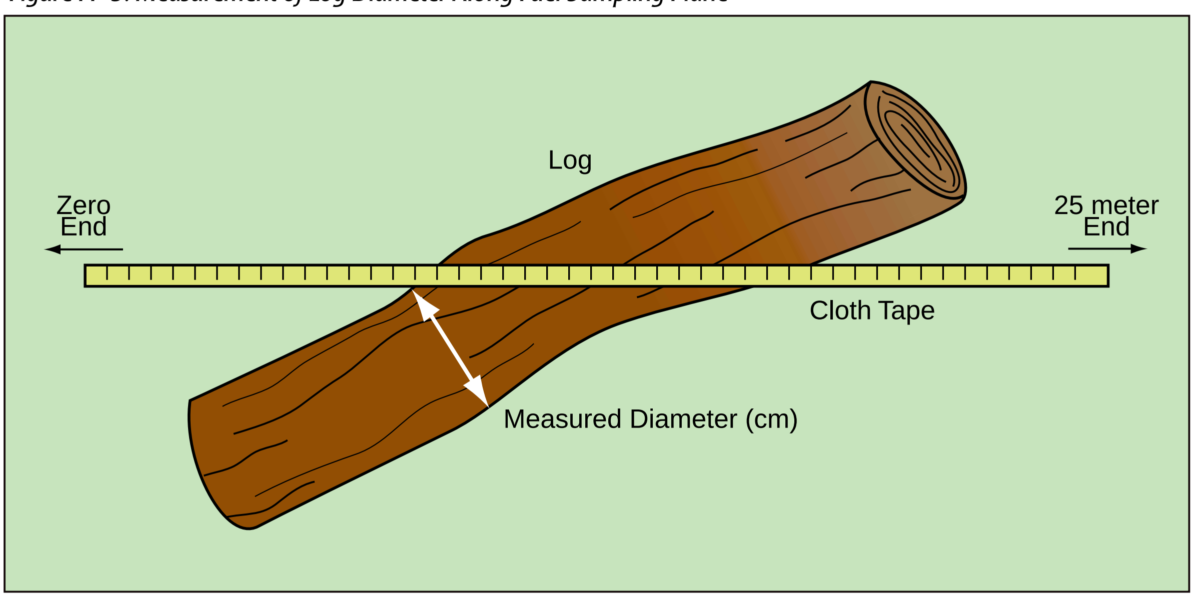
2. Work with another student who is approximately your same height. Stand at the start of the transect. Your partner stands at the 25-meter mark. Look through the straw of the clinometer and locate the eyes of the other student. Record the angle on the *Transect Measurements Data Sheet*. If you are looking downhill, turn the clinometer around, locate the eyes of the other student and record angle.
3. Walk to the 5-meter mark on the tape and start counting the downed woody fuel intersects. Figure FF-4 shows the sampling strategy.

Measuring fuels is quite simple. All you need to do is count the number of downed woody particles by size class that cross the vertical sampling plane (see Figure FF-3). Remember, the diameter of the fuel particle is determined where the particle crosses the sampling plane. Use the wooden dowels to decide the size of each woody fuel particle that intersects the plane. Use the clear plastic ruler to measure the 8+ cm logs. Do not count fuels below the litter layer (sunken in the ground), or if the dead woody fuel is attached to a live plant. Also, be careful to only count woody material. Many herbaceous stems look like twigs once they are on the ground, so pick up a few questionable twigs and snap them in two to make sure the center is solid wood. Also, be sure not to tally needle intersections, especially large needles such as those fallen from pine trees.

If you are working in a group of 3, each person can keep track of one size of fuel as you walk along the transect. Then all the size class of fuels, except the largest (8+ cm) can be counted at once. If you are working in a group of 2 or by yourself, sometimes it helps if you count only one fuel type (e.g., 0 – 1 cm) first, then go back and count the 1 – 3 cm and 3 – 8 cm fuels. This is especially helpful if you are in heavy fuel loadings. Be careful not to disturb the fuels.

4. Measure the diameter of the 8+ cm logs to the nearest centimeter by laying the clear plastic ruler along the log cross section, perpendicular to the long axis of the log at the point where the vertical sampling plane intersects the log (Figure FF-5). Sometimes, the tape may be oriented nearly parallel to the log, so you will need to take the log diameter where the tape first touches the log from the zero end.
5. Measure the log decay class for each log 8+ cm in diameter. Five log decay classes are used to describe the stages of decay for each log. These classes are important because heavily decayed logs are difficult to ignite and do not contain as much

Figure FF-5: Measurement of Log Diameter Along Fuel Sampling Plane



biomass as sound logs. Classes 1, 2, and 3 are called sound logs because when you kick them, no parts of the log are dislodged. Classes 4 and 5 are called rotten logs because when you kick them they break apart or a piece of the log becomes dislodged. Record both the diameter and log decay class on the data sheet for each log.

- Class 1 is for newly fallen logs where the leaves are still on twigs attached to the logs, and the logs are still green (contain fresh sap).
- Class 2 logs have no leaves but still contain the bark and a majority of small and large twigs and branches. The logs have dried centers and there is no sign of fresh sap or live tissue.
- Class 3 logs do not have any bark and have lost most twigs and branches. These logs are typically gray and their centers have not yet rotted.
- Class 4 logs are still somewhat intact and, when you kick them, only small pieces become loose. Be sure to measure the log diameter before you kick to determine rot class. Often the inside of the logs have rotted and the outside shell is the only part of the log still somewhat sound.
- Class 5 logs are fully rotten and often completely fall apart when you kick them. Sometimes it is difficult to identify a rotten, Class 5 log because it is so decomposed it seems part of the litter and duff. Do not measure these Class 5 logs because they act more like duff than logs when they burn. A good way to decide whether or not to measure a Class 5 log is to estimate if the log has collapsed to less than half of the original diameter where it crosses the tape. If the rotted diameter is less than half the original, then do not consider it a log and skip it.

Note: Do not measure the following:

- Dead limbs extending from standing live or dead trees or shrubs.
- Stumps and roots because they rarely burn in a wildland fire.
- Logs that intersect the sampling plane above 2 meters. This especially means those dead tree trunks or branches leaning over the sampling plane. If tree trunks lean below the 2-meter height, then record them as downed logs as long as they are totally dead.

6. After collecting the data between the 5- and 7-meter marks, walk to the 10-meter mark. Count the 3 – 8 cm and the 8+ cm logs. Measure the diameters and identify the rot class of the 8+ cm logs.
7. Walk to the 15-meter mark. Count the 8+ cm logs. Measure the diameters and identify the rot class of the 8+ cm logs.

Part 2: Measurements taken at the 15-meter mark

8. At the 15-meter mark estimate the depth of litter and duff, and the cover and height of live and dead shrub and herbaceous plants. Cover is estimated within a circle with a 1-meter radius. The center is at the 15-meter mark. Here is what you do:

First, estimate the vertically projected cover of live shrubs in the 1-meter radius circle. Shrubs are

Table FF-2: Cover Classes

Cover Class	Percent
01	Less than 1 %
03	1 to 5%
10	5 to 15%
20	15 to 25%
30	25 to 35%
40	35 to 45%
50	45 to 55%
60	55 to 65%
70	65 to 75%
80	75 to 85%
90	85 to 95%
99	95 to 100%

those plants that have woody stems and include some of the creeping vine-like plants on the ground and young, short trees (called tree regeneration). Check the plants to see if they have woody stems. Use the cover classes listed in Table FF-2.

Two points on that circle are already provided for you by the 14- and 16-meter marks. However, you will need to estimate, by eye, the radius of the circle perpendicular to the tape. A good way to do this is to stand directly above the 15-meter mark and extend your arms outward. Be sure to measure your arm span and adjust your estimates. Confine the cover estimate of live shrubs and tree regeneration to the 2-meter height limit.

a. Now inspect the shrubs and tree regeneration more closely. Notice the dead material still attached to the shrubs and small trees. This includes dead leaves, branches, flowers, and so on. Try to estimate the cover of these dead plant parts using the same cover classes. Do not add those shrub branches that are unattached and lying on the ground.
b. Estimate the average height of the live shrubs within your circle. Find the shrub layer that has the most (greater than 50 percent cover) canopy cover and measure the vertical height from the top of the litter layer to the height of the dominant layer. Shrub heights can be quite variable. A quick way to estimate shrub heights is to accurately measure the heights of your ankle, knee, and waist so you can use those known heights to estimate the plant heights. A better way is to measure plant heights with a meter stick. Enter heights that are less than 5 cm as zero.
c. Next, look around your 1-meter radius circular plot and estimate the percent cover of live herbaceous ground cover using cover classes in Table FF-2. Include all ferns, moss, grasses, sedges, lichens, and forbs below the 2-meter height threshold.
d. Then, estimate the percent dead herbaceous ground cover using the same cover classes.
e. Estimate the height of the live herbaceous layer using the meter stick.
f. Estimate the height of the dead herbaceous layer using the meter stick.

9. Still at the 15-meter mark, you next measure the thickness of litter and duff. Litter and duff burn differently and both are needed to accurately predict fire consumption. Litter is generally consumed by flaming combustion while the duff is consumed by smoldering combustion. Litter is composed of freshly deposited leaf, needle, and other plant parts, while the duff is made up of decomposing organic matter. Plant parts can be identified in the litter, but not so easily in the duff. The duff is generally moist, heavy, dense, and dark, while the litter tends to be drier, less dense and lighter color. It can be difficult to estimate where the litter stops and duff starts. So do the best you can.

   The depth of the litter and duff layer is measured at the 15-meter mark at approximately 20 centimeters to the right of the transect as you are looking from the zero end towards the 25 meter end (i.e., the south side of the tape on the first transect). If there is a tree, log, rock, or stump at the 20 cm offset distance, take a measurement 20 cm to the left of the transect. If a suitable sampling place is still not available, pick a place as close to the 20 cm distance as possible that is somewhat representative of the duff and litter layer characteristics within the 1-meter radius plot. Do not go beyond 30 cm from the 15- meter tape mark on either side of the tape. If no place is available to measure duff and litter, enter zero for total litter and duff depth and duff depth on the *Fire Fuel Transect Measurements Data Sheet*.
   Litter and duff depths will be highly variable across a stand so be prepared for a wide variety of measurements. Duff and litter depths generally increase near trees, especially near tree stems where needles

and leaves accumulate. Be sure to dig all the way to the mineral soil surface because sometimes the duff and litter layer is so deep that it is often hard to tell when you hit the mineral soil interface. This is especially true when the depth measurement has to be taken directly where a log has been decomposing to form a seemingly deep duff layer. If unsure where the mineral soil starts, try digging a test hole just down the tape (towards the zero end) to make sure you know what the mineral soil looks like and what conditions might indicate where the mineral soil starts.

a. Use the garden trowel to cut through the litter and duff layer to the mineral soil.
b. Pull one side of the cut layer away to reveal the litter/duff profile.
c. Place the clear ruler against the profile with the zero end of the ruler at the bottom of the profile. Measure the depth of the entire profile. Record the depth on the *Fire Fuel Transect Measurements Data Sheet*.
d. Next, slide your finger down the ruler until it touches the top of the duff layer. Grasp the ruler tightly without moving your finger and bring the ruler up to your face so that you can read the centimeter scale at the bottom of your finger. Record the depth of the duff layer.

Part 3: Measurements taken between the 15 and 25-meter marks

10. Walk to the 25-meter mark. Count all the 8+ cm diameter logs that intersect the transect up to 2 meters high. Measure the diameters and identify the log decay class of the 8+ cm logs.

Part 4: Measurements taken at the 25-meter mark

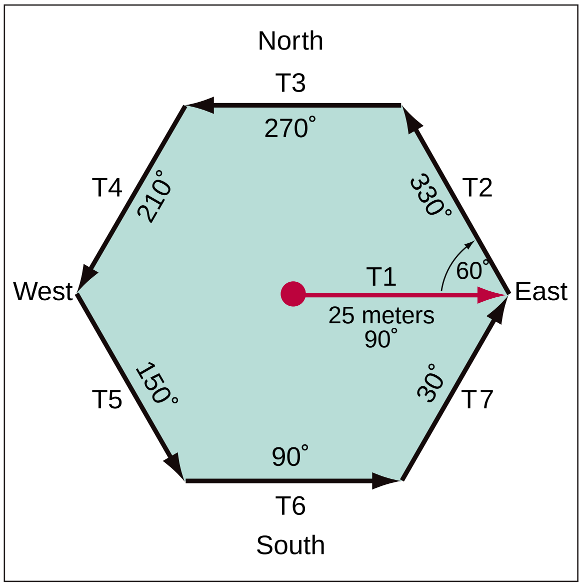
11. At the 25-meter mark, repeat steps 8 and 9.

After you get to the 25-meter mark and have measured transect slope, tallied all the woody intersects, estimated dead and live shrub and herbaceous height and cover, and measured total litter/duff depth and duff depth at the 15- and 25-meter marks, the transect is finished. You can reach down and pull on the tape to dislodge the nail at the zero end of the transect. Don't worry about disturbing the fuel bed at the end of the tape because the next transect, offset at 60 degrees from this transect, will again start at the 5 meter mark. Always check and make sure that you have recorded all the data for the transect in your *Fire Fuel Transect Measurements Data Sheet* before dislodging the tape. The slope of the transect is almost always the one measurement people forget to write down, so check to make sure you have measured and recorded the transect slope.

Part 5: Repeat measurements along next transect

12. The next transect (transect number 2 on your plot sheet) is established at a 60˚ angle from the first transect at an azimuth of 330˚ (Figure FF-6). Repeat steps 1 through 11. An azimuth of 270º is used for the third transect. Repeat steps 1 through 11. If after you measured fuels on the first three transects and there are less than 100 intersections for all wood classes combined (0 –1 cm, 1 – 3 cm, 3— 8 cm, and 8+ cm), then take additional transects in the order and direction shown in Figure FF-6 going counter-clockwise around the center of the plot. Stop taking measurements after 100 intersects are counted for all size classes combined. However, the entire transect must be finished even if you reach a 100 midway through a transect. Measure at least three transects to get 100 intersections for all fuel size classes, but no more than 7 transects. If you still haven't counted 100 intersections by transect number seven, stop after completing transect 7.

Figure FF-6: Direction and Distances for Each Fuel Transect Established in a Stand



Frequently Asked Questions

1. Why do we have to measure both live and dead herbaceous plants?

The distinction between live and dead herbaceous is somewhat arbitrary because it is highly dependent on phenology and season of sampling. After all, most herbaceous plants will eventually be dead by the end of the growing season, so why distinguish between the two? This is done to reference phenological conditions at your site. Since you recorded the date, these data will help fire modelers create fire danger models that predict phenology of the herbaceous material over the course of the year.

2. If it is difficult to distinguish between litter and duff, why try?

Litter and duff burn differently. Litter is generally consumed by flaming combustion while the duff is composed by smoldering combustion. This is because the moisture content and types of material that can be burned are different.

Acceptable Measurement Errors

1, 10, hour fuels	± 3 intersections of 100 intersections
100, 1000 hour fuels	± 1 intersections out of 100 intersections
1000 log diameters	± 2 cm
1000 log rot class	± 1 class
Live and dead herbaceous cover	± 5 percent cover
Live and dead shrub cover	± 5 percent cover
Duff and litter depth	± 0.5 cm
Percent litter that is duff	± 5 percent
Crown height	± 0.1 meter < 2 meters tall, ± 0.5 meter > 2 meters tall
Stand height	± 2 meters > 15 meters tall, ±0.1 meters < 15 meters tall
Canopy closure	± 5 percent
GPS coordinates	± 0.001 decimal degrees, ± 10 meters UTM coordinates
Slope	± 3 percent
Aspect	± 5 degrees
Elevation	± 30 meters

3. We have a homogeneous land cover site, but it looks like the woody material is not evenly spread out. What should we do?

Pick a place that best represents the conditions in the stand based on the vegetation (species composition, plant structure, plant size, canopy closure), the stand's history (stumps, burned logs, fire scars), ground (fuel loadings, duff depths), and most importantly, topography (slope, aspect, elevation). If there is variability, then you may want to sample multiple plots within the stand to capture the entire range of variation.

4. What is the best way to estimate the average heights of the dominant stratum and base of crowns in the lowest stratum?

If the trees or shrubs you measured for the canopy or in the dominant stratum, then you can average those measurements of heights. If not, you can either estimate the average height by looking at your site without taking any measurements, or take additional tree or shrub height measurements to calculate an average. Take enough measurements so that you feel confident in the estimate of dominant stratum height and base of crown in the lowest stratum height.

Fire Fuel Protocol: Center Plot Measurements

Field Guide

Task

To describe the general characteristics of the Fire Fuel Site by performing the *Land Cover Sample Site* and *Biometry Protocols* in the *Land Cover/Biology Investigation* as well as measuring slope, aspect, and average stand and crown heights.

What You Need

- ❑ *Fire Fuel Center Plot Data Sheet*
- ❑ *GPS Data Sheet*
- ❑ *The Center Plot Fire Fuel Guide*
- ❑ *MUC Field Guide* or *MUC Glossary of Terms*
- ❑ *Data Sheets* and *Field Guides* for the *Land Cover Sample Site and Biometry Protocols* in the *Land Cover/Biology Investigation*
- ❑ GPS receiver
- ❑ Wooden stakes or flags
- ❑ Flexible tape measure, at least 30 meters
- ❑ Compass
- ❑ Clinometer
- ❑ Tree guides
- ❑ Meter stick
- ❑ Clipboard
- ❑ Pencils or pens
- ❑ Colorful flagging (optional)
- ❑ Camera

In the Field

1. Do the *Land Cover Sample Site* and *Biometry Protocols* in the Land Cover/Biology Investigation. Identify latitude, longitude and elevation using a GPS, take photos and identify the MUC class. Do the full set of biometry measurements: ground and canopy cover, tree and shrub heights, dominant and codominant tree and shrub species identification.
2. Measure the aspect of the site. Stand perpendicular to the slope of the site with your eyes facing uphill. Measure the direction with the compass (1-360 degrees). Be sure to enter the true not magnetic directions. An aspect value of zero is entered for flat stands with no slope. 360 degrees is used for true north.
3. Work with another student who is approximately your same height. Measure the angle of the slope of the site by aiming your clinometer downhill 25 meters away. Look through the straw of the clinometer and locate the eyes of the other student. Record the angle on the *Fire Fuel Transect Measurements Data Sheet*. If you are looking downhill, turn the clinometer around, locate the eyes of the other student and record angle. Then, look upslope and repeat the procedure. Record second slope value.
4. Estimate the height of the trees or shrubs in the dominant stratum greater than 2 meters. To be considered a tree or shrub stratum, there needs to be at least 10% canopy cover.
5. Measure the heights of the base of the crowns of trees or shrubs in the lowest stratum. To be considered a tree or shrub stratum, there needs to be at least 10% canopy cover. The trees or shrubs must be greater than 2 meters tall. Calculate the average height.
6. Record any comments that may be relevant to the fuels data.

Fire Fuel Protocol: Transect Measurements

Field Guide

Task

Multiple measurements will be taken:

1. Slopes of individual transects,
2. Counts of the different sizes of downed woody fuel types,
3. Diameters and rot classes of logs greater than 8 cm,
4. Canopy cover and heights of shrubs less than 2-meters tall,
5. Herbaceous cover, and
6. Depths of litter and duff.

What You Need

- ❑ *Fire Fuel Transect Measurements Data Sheet*
- ❑ Wooden stakes
- ❑ Flexible tape measure, at least 30 meters
- ❑ Compass
- ❑ Clinometer
- ❑ 0.5-0.65 cm wooden dowel
- ❑ 2.5 wooden dowel
- ❑ 2 clear rulers in mm
- ❑ Meter stick
- ❑ Garden trowel
- ❑ Clipboard
- ❑ Pencils or pens
- ❑ Colorful tape or flagging (optional)

In the Field

Part 1: Measurements taken between the 5-meter and 15-meter marks along a transect

1. From the center of the site, lay a flexible tape measure due East (90˚) for 30 meters. Keep the tape measure as tight and straight as possible.
2. If not already done, mark the 5- meter, 7-meter, 10-meter, 15-meter, and 25-meter distances with colorful tape or flagging.
3. Use a clinometer to measure the slope of the site. Pick two students of approximately the same height. One student stands at the start of the transect with the clinometer while the other student walks 25 meters away down the slope. The student with the clinometer sights the eye of the other student and records the angle.
4. Starting at the 5-meter mark, walk to the 7-meter mark. Count the 0-1 cm, 1-3 cm, 3-8 cm, and 8+ cm fuel particles that cross the sampling plane of the transect between the 5 and 7-meter section of the transect. The sample plane starts at the ground surface and extends exactly 2 meters directly vertical above the ground surface. The diameter of the fuel particle is determined exactly where the particle crosses the sampling plane from the zero end. Use the 0.5-0.65 cm and 2.5 dowels and ruler to estimate size categories.

5. Use the ruler to measure the diameter of the downed woody fuel with diameters greater than 8 cm. Measure the diameter where the log crosses the sampling plane and perpendicular to the long axis of the log. Record the log decay class of each log (see Table FF-2).
6. Continue walking to the 10-meter mark. Count all 3-8 cm and greater than 8 cm downed fuel particles. Use the ruler to measure the diameter of the downed woody fuel greater than 8 cm. Record the log decay class of each log greater than 8 cm.
7. Continue walking to the 15-meter mark. Only count the downed woody fuel greater than 8 cm in diameter. Measure the diameter and record rot class for each log.

Part 2: Measurements taken at the 15-meter mark

8. At the 15-meter mark, estimate the canopy cover of live shrubs less than 2-meters tall within a circle that has a 1-meter radius. Make sure the plants have woody stems. Use the cover classes shown in Table FF-3.
9. Use the meter stick to estimate the average height of the live shrubs. Measure to the nearest 10 cm.
10. Estimate the cover of the dead parts of the shrubs less than 2-meters tall within the circle. Do not add those shrub branches that are unattached and lying on the ground. Use the cover classes shown in Table FF-3.
11. Use the meter stick to estimate the height of the dead shrub layer. Measure to the nearest 10 cm.
12. Estimate the percent cover of live herbaceous plants within the circle. Use the cover classes shown in Table FF-3.
13. Estimate the height of the live herbaceous layer
14. Estimate the percent cover of dead herbaceous plants within the circle. Use the cover classes shown in Table FF-3.
15. Estimate the height of the dead herbaceous layer
16. Between 20 and 30 cm to the right (as you face the end of the transect) of the 15-meter mark, use a garden trowel to cut through the litter and duff to the mineral soil. Try not to compress the litter and duff layer. Place the ruler with 0 end next to the mineral soil. Measure the thickness of the entire litter/duff layer with the ruler. If no place is available to measure duff and litter, enter '0' for duff and litter depth on data sheet.
17. Measure the thickness of the duff layer.

Part 3: Measurements taken between the 15 and 25-meter marks

18. Walk to the 25-meter mark. Count the downed woody fuel greater than 8 cm in diameter. Measure the diameter and record log decay class for each log.

Part 4: Measurements taken at the 25-meter mark

19. Repeat steps 8-17 for the 25-meter mark. These are the same measurements taken at the 15-meter mark.

Part 5: Repeat measurements along next transect

20. At the end of the transect, point the compass in a 330˚ direction. Lay a flexible tape measure in the 330˚ direction for 30 meters. Keep the tape measure as tight and straight as possible.
21. Repeat steps 2-19.
22. At the end of the transect, point the compass in a 210˚ direction. Lay a flexible tape measure in the 210˚ direction for 30 meters. Keep the tape measure as tight and straight as possible.
23. Repeat steps 2-19.
24. A total of 100 fuel particles for all size classes combined is requested. If this has not been reached, then lay out another transect in the 150˚ and repeat steps 2-19. A total of 7 transects can be measured as shown in Figure 3.

References

Brown, J.K. 1971. *A planar intersect method for sampling fuel volume and surface area.* Forest Science 17(1):96-102.

Brown, J.K. 1974. *Handbook for inventorying downed woody material.* USDA Forest Service General Technical Report INT-16. 22 pages.

Brown, J.K. and P.J. Roussopoulos. 1974. *Eliminating biases in the planar intersect method for estimating volumes of small fuels.* Forest Science 20(4):350-356.

Van Wagner, C.E. 1968. *The line intersect method in forest fuel sampling.* Forest Science 14(1):20-31.

Glossary

Arboreal
Plants living in or on trees

Aspect
The general down slope direction the stand faces

Biota
All living things within an ecosystem

Biomass
Biologically derived organic material within an ecosystem. Biomass can be live (green biomass) and dead (necromass)

Downed, dead woody fuels
Dead woody fuels found on the ground. Dead fuels no longer manufacture food or circulate water so their moisture contents are more closely linked to atmospheric conditions. These are the most important for wildfire spread and the most influential for subsequent fire effects.

Duff
Composed of primarily decomposing organic matter. The duff is generally moist, heavy, dense, and dark.

Fire effects
The damage or influence a fire has on the biota

Fire intensity
The flame length

Fire severity
A term quantifying fire effects. Severity is the damage that heat from fire on living organisms above and below ground.

Fire spread
How fast a fire moves

Ha
Abbreviation for hectare or 10,000 square meters

Live fuels
Those biomass pools that are living plants extracting water from the soil

Litter
Composed of freshly deposited leaf, needle and other plant parts. Plant parts are readily identifiable in the litter.

Loading
The weight or mass of dead or live fuels per unit area (e.g., kg m^{-2})

Phenology
The study of recurring biological cycles and their connection to climate

Stand
An area of homogenous vegetation and fuel conditions usually delineated by the dominant vegetation type

Fire Fuel Protocol:

Center Plot Data Sheet

School Name: ____________________

Observer Names: ____________________

Date: __________ Study Site Name (give your site a unique name): __________

Aspect: __________ degrees True North (enter 0 for sites with no slope)

Overall slope of stand: looking up __________ slope degrees   looking down __________ slope degrees

Heights of trees or shrubs in dominant stratum:

Tree or Shrub	Height(m)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Average height of dominant stratum = (sum of heights) ÷ (total number of trees and shrubs)

Average height: __________

Heights of the base of crowns in lowest stratum:

Tree or Shrub	Height(m)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Average height of base of crowns = (sum of heights) ÷ (total number of trees and shrubs)

Average height: __________

Comments: ____________________

Fire Fuel Protocol:
Transect Measurements Data Sheet

School Name: ______________________________

Observer Names: ______________________________

Date: ____________ Study Site Name (give your site a unique name): ____________

Number of Transects: ____________

Woody Fuel Counts

	Transect 1	Transect 2	Transect 3	Transect 4
Direction of transect (True North)	90°	330°	270°	210°
Slope of transect (degrees)				
0-1 cm diameters (5-7 m mark)				
1-3 cm diameters (5-10 m mark)				
3-8 cm diameters (5-25 m mark)				

	Transect 5	Transect 6	Transect 7
Direction of transect (True North)	150°	90°	30°
Slope of transect (degrees)			
0-1 cm diameters (5-7 m mark)			
1-3 cm diameters (5-10 m mark)			
3-8 cm diameters (5-25 m mark)			

8+ cm Diameters and Log Decay Classes (between 5-25 m along transect)

LDC = Log Decay Class

Log	Transect 1	Transect 2	Transect 3	Transect 4
Azimuth (True North)	90°	330°	270°	210°
	Diameter (cm)/ LDC	Diameter (cm)/ LDC	Diameter (cm)/ LDC	Diameter (cm)/ LDC
1	/	/	/	/
2	/	/	/	/
3	/	/	/	/
4	/	/	/	/
5	/	/	/	/
6	/	/	/	/
7	/	/	/	/
8	/	/	/	/
9	/	/	/	/
10	/	/	/	/

Log	Transect 5	Transect 6	Transect 37
Azimuth (True North)	150°	90°	30°
	Diameter (cm)/ LDC	Diameter (cm)/ LDC	Diameter (cm)/ LDC
1	/	/	/
2	/	/	/
3	/	/	/
4	/	/	/
5	/	/	/
6	/	/	/
7	/	/	/
8	/	/	/
9	/	/	/
10	/	/	/

LDC-Log Decay Classes

1 = sound, needles intact (green or brown)
2 = sound, bark and branches present
3 = sound, bark partially intact, branches gone
4 = rotten, bark and branches gone
5 = rotten, more than half the log diameter above soil surface

Summary of 8 +cm logs

	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7
Total 8+ cm logs							
Total rot class 1 logs							
Total rot class 2 logs							
Total rot class 3 logs							
Total rot class 4 logs							
Total rot class 5 logs							

Shrub - Dead and Live Cover and Height Estimates at 15 m and 25 m Mark

	Transect 1	Transect 2	Transect 3	Transect 4
Azimuth (True North)	90°	330°	270°	210°
	Live / Dead	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/	/
Height 15 m mark (cm)	/	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/	/
Height 25 m mark (cm)	/	/	/	/

	Transect 5	Transect 6	Transect 7
Azimuth (True North)	150°	90°	30°
	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/
Height 15 m mark (cm)	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/
Height 25 m mark (cm)	/	/	/

Cover Class	Percent
01	Less than 1 %
03	1 to 5%
10	5 to 15%
20	15 to 25%
30	25 to 35%
40	35 to 45%
50	45 to 55%
60	55 to 65%
70	65 to 75%
80	75 to 85%
90	85 to 95%
99	95 to 100%

Herbaceous - Dead and Live Cover and Height Estimates at 15 m and 25 m Mark

	Transect 1	**Transect 2**	**Transect 3**	**Transect 4**
Azimuth (True North)	90˚	330˚	270˚	210˚
	Live / Dead	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/	/
Height 15 m mark (cm)	/	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/	/
Height 25 m mark (cm)	/	/	/	/

	Transect 5	**Transect 6**	**Transect 7**
Azimuth (True North)	150˚	90˚	30˚
	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/
Height 15 m mark (cm)	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/
Height 25 m mark (cm)	/	/	/

Duff and Litter - Depth Measurements in Centimeters at 15 m and 25 m Mark

	Transect 1	**Transect 2**	**Transect 3**	**Transect 4**
Azimuth (True North)	90˚	330˚	270˚	210˚
	Total Depth/ Duff Depth	Total Depth/ Duff Depth	Total Depth/ Duff Depth	Total Depth/ Duff Depth
15 m mark (cm)	/	/	/	/
25 m mark (cm)	/	/	/	/

	Transect 5	**Transect 6**	**Transect 7**
Azimuth (True North)	150˚	90˚	30˚
	Total Depth/ Duff Depth	Total Depth/ Duff Depth	Total Depth/ Duff Depth
15 m mark (cm)	/	/	/
25 m mark (cm)	/	/	/

Table FF-3: Fuel Types and Size Classes Used in Fire Management. The classes of fuels used in this protocol. The diameters of the downed wood are often referred to the average length of time it takes to dry the wood.

Fuel Type	**Size** (twig, branch, or trunk diameter)	**Description**
Crown Foliage	Any	Living and dead crown foliage including needles and broad leaves
Crown Branchwood	0 to 3 cm	Live and dead crown woody branches
Shrub — Live	Any	Living woody plants – trees and shrubs less than 2 meters tall
Shrub — Dead	Any	Dead shrubby material suspended above ground. This includes trees and shrubs less than 2 meters tall.
Herbaceous - Live	Any	Live herbaceous plants including grasses, sedges, forbs, ferns, and lichen
Herbaceous — Dead	Any	Dead herbaceous plant parts above ground
Litter	None	Recently fallen needles, leaves, cones, and bark
Duff	None	Partially decomposed organic material below the litter layer
Downed Woody	0 to 1 cm	Takes 1 hour to dry woody twigs and branches
	1 to 3 cm	Takes 10 hours to dry woody twigs and branches
	3 to 8 cm	Takes 100 hours to dry woody branches
	8 + cm	Takes 1000 or more hours to dry branches and logs